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VIRUS DISEASES OF PLANTS IN ARIZONA. I. FIELD AND EXPERIMENTAL OBSERVATIONS ON MOSAICS AFFECTING VEGETABLE CROPS

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COVER

Symptoms of mosaic virus infection in leaves of carrot. Leaf at left has a finely dissected margin. Right hand leaf lighter than normal in color (chlorotic). Center leaf is normal.

SUMMARY

Mosaic viruses cause considerable losses in vegetables in Arizona. The effect on the plant of these invisible disease-inducing agents may assume the form of (a) sudden decline and death, (b) slow decline and death, or (c) unsightly appearance of affected plants or plant parts. Some mosaic viruses, such as those causing flower color breaking, enhance the appearance of the affected plant by inducing desirable and spectacular variegations. Flower color breaking viruses occur more frequently in ornamental than in crop plants.

Symptoms due to various strains of cucumber and tobacco mosaic viruses are those most frequently encountered in the field in Arizona. Other mosaic viruses occur less frequently.

Mosaic viruses may cause a wide variety of reactions in leaves, stems, flowers, and fruits of infected plants. Some of the usual leaf symptoms are: mottling in the form of diffuse, ringspot or wavy line-patterns, reduction in size; alteration in shape; and puckering or roughening of the surface. Stems react in much the same manner as do leaves. One of the outstanding stem symptoms consists of a shortening of the internodes, resulting in a close position of the leaves. In such crops as lettuce, mosaic virus infections may cause plants to fail to head.

Fruits of some crops may be mottled or altered in shape and size, in addition to lacking quality and flavor. The sugar content of mosaic virus-infected melons is low.

Unless infection is severe, roots generally do not show symptoms of mosaic virus attack. In severe infections roots may become stunted and their ability to function normally is impaired.

Mosaic viruses may spread in one or more of several ways: (a) seeds, (b) insects, and (c) various mechanical methods. Cucumber mosaic virus strains are spread by all three methods. As far as is known, tobacco mosaic virus which may affect tomato, pepper, and eggplant in Arizona is disseminated through mechanical agencies such as man and machinery. Tobacco mosaic viruses are also spread through non-processed and processed chewing and smoking tobaccos.

Complete control of mosaic viruses is virtually impossible. Some of the suggestions advanced to reduce losses from these diseases are: (a) use of disease-free seed, (b) eradication of infected plants, (c) sanitation, including the elimination of susceptible weeds both from within the crop and the surrounding areas, (d) isolation of crops susceptible to the same virus strains, (e) use of suitable insecticides against the insect vectors of mosaic viruses, (f) natural or physical barriers such as mountains, tree rows, and buildings afford, (g) use of resistant varieties of plants which are available for only a few vegetable and field crops, (h) crop-free periods, and (i) other measures such as trap crops, direct seeding of vegetables in the field, and elimination of careless handling of tobacco by workmen while working in such crops as tomato, eggplant, and pepper.

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VIRUS DISEASES OF PLANTS IN ARIZONA. I. FIELD AND EXPERIMENTAL OBSERVATIONS ON MOSAICS AFFECTING VEGETABLE CROPS

By Paul D. Keener [1]

INTRODUCTION

Viruses are extremely small, disease-inducing agents. So far as is known, they thrive only in living cells and tissues of animals and plants.

Unlike plants invaded by bacteria and fungi in which some external sign of the causal organism is noticeable, plants infected by viruses offer only indirect evidence of illness. In fact, disease symptoms may be entirely absent in plants invaded by viruses. In such cases, the invaded plants function as symptomless carriers. When symptoms are obscure or lacking, it is necessary to perform extensive, time-consuming tests in order to determine the particular virus present. Such tests, involving direct inoculations and insect feedings, are made on highly susceptible indicator plants.

Plants usually react in some definite manner to virus infections. Many types of symptoms occur. Some of these are quite distinct and therefore obvious to an observer; others are less so and may intergrade, resulting in confusion as to the actual cause of a disorder.

Whereas bacteria and fungi can be observed with the customary light microscopes in use in modern laboratories today, viruses are so minute that observation is impossible without the aid of highly specialized equipment. The electron microscope fills this need, and although such instruments are extremely expensive, they are being used in some laboratories for diagnosis of plant and animal virus diseases.

This bulletin is the first from this state dealing exclusively with virus diseases of vegetables in Arizona. Material for the bulletin was derived from several sources and constitutes a summary of all of the pertinent vegetable mosaic virus information available in the state at this time. Field observations have been conducted throughout the state for many years by past and present members of the Department of Plant Pathology, University of Arizona, Tucson. These form the chief source of information for the present publication. Records available up to January 1, 1954, in this Department and the Agricultural Experiment Station, are included. In addition, the results of experiments performed by the writer since 1949 are included wherever necessary for the clarification of the discussion.

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[1] Department of Plant Pathology, Agricultural Experiment Station, University of Arizona, Tucson.

ECONOMIC SIGNIFICANCE OF PLANT VIRUSES AND VIRUS DISEASES

The amount of damage caused by a virus in a plant depends on several factors, among which are: (a) the age of the plant at the time of infection, (b) the period of time the crop must survive an attack before harvest, (c) the nature of the attacking virus, and (d) the initial amount of virus inserted into the plant. The last-mentioned factor is extremely significant with insect-transmitted types, and it may also be important with viruses that are mechanically-transmitted through infected plant juices and through seeds.

Losses resulting from virus attacks may assume the form of (a) sudden decline and death, (b) slow decline and death, and (c) losses due to the unsightly appearance of the infected plants.

Sudden decline and death—The mosaic viruses identified up to the present time in Arizona vegetables seldom cause sudden decline and death.

Slow decline and death—Most of the losses due to mosaic virus infections in vegetables in Arizona are due to gradual decline and ultimate death of the infected plants. Some disfigurement of certain crops also occurs.

Numerous and widely distributed viruses cause the diseases known as mosaics. In some seasons mosaic viruses are more prevalent and destructive than they are in others. Certain valleys, notably the Yuma and Deer in Arizona, and the Imperial in California have been localities in which heavy losses from mosaic viruses have occurred in melons, especially in cantaloupes and honeydews. At times, there have been losses from strains of lettuce mosaic virus. Melon and lettuce mosaic virus infections occur every year in Arizona. The severity of these infections fluctuates from year to year and from one locality to another. In the case of these viruses, unless attacks are sufficiently severe to necessitate the total destruction of the crop, losses in dollar values are difficult to assess.

In 1945-46, yellow-spot virus, which is part of the mosaic picture, caused losses in two plantings of Giant Pascal Celery. In these instances, growers estimated their losses at $14,000 in a 22-acre stand in the Santa Cruz Valley and $25,000 in a 23-acre planting in Deer Valley.

In Europe, the gradual decline of certain potato varieties was at first thought to be the result of continuous vegetative propagation. It is now recognized as having been caused by such pathogens as the potato leafroll and rugose mosaic viruses. Both of these viruses commonly infect potatoes in Arizona and are partially responsible for the periodic changes in seed source which the Arizona grower finds desirable.

Losses due to the unsightly appearance of affected plants—Many viruses appear to be able to live harmoniously, almost perpetually, within their hosts without causing any appreciable effect other than a change in the appearance of the affected plants.

In Arizona, and elsewhere, squash mosaic virus strains cause intense mottling and wart-like outgrowths on infected fruit surfaces. Tomato fruits infected with tobacco and cucumber mosaic viruses become blemished with unsightly spots and often are malformed. When blemishing alone occurs, the fruits are usually of normal size and shape but are unattractive to the housewife.

Among ornamental plant viruses, some of which infect vegetable crops, is fig mosaic. The leaves and at times the fruits of fig trees infected with this virus are unsightly. The virus appears to live for years in constant harmless association with the host.

Beneficial effcts of virus attack—Fortunately, for some nurserymen, mosaic viruses are not at all destructive and enhance the value, desirability, and marketability of the infected plants (See page 17).

MOSAIC SYMPTOMS—GENERAL

Difficulties immediately arise when attempts are made to describe some of the symptoms which mosaic viruses induce in susceptible plants. The same virus may cause different symptoms in different plants, for example, tobacco mosaic virus in tomato, eggplant, and pepper and in certain species of *Nicotiana*, the genus to which tobaccos belong. (Compare Plates IV, *B, C;* V, *A* with Plates XVII and XVIII). On the other hand, altogether different viruses affecting the same host may cause similar symptoms. For example, field symptoms induced by the lettuce mosaic virus in Arizona frequently simulate those caused by the big-vein virus in the same crop. In the light of our present knowledge, these viruses are entirely different pathogens.

In spite of the difficulties frequently prevailing in ascertaining the virus actually responsible for a specific set of reactions, the symptoms within certain limits are describable. An attempt is made in this bulletin to describe and illustrate the most common and easily recognizable symptoms induced by mosaic viruses in vegetable crops and other significant plants in the field in Arizona.

Some of the most frequently-encountered symptoms of mosaics in vegetables in Arizona are those caused by various strains of tobacco and cucumber mosaic viruses. Other mosaics may occur to a limited extent, but the viruses belonging to the tobacco and cucumber groups appear to be widespread and destructive.

Lettuce mosaic in Arizona seems to be distinct from those virus strains causing mosaics in cucurbits such as cantaloupes, honeydew melons, watermelons and squashes.[2] Cucumber mo-

Mosaic viruses may infect susceptible hosts at any stage of development. Plants infected during the seedling stage usually saics have been reported in lettuce in other parts of the world.

[2] Experimental transmission studies with a seed-borne mosaic virus in Imperial 615 and 749 lettuce, at Tucson in 1952, indicated that the virus will not infect cantaloupe, honeydew, pepper, or tobacco. Such infection would be expected if one of the cucumber mosaic viruses is involved.

Plate I.—Symptoms of yellow-mottle (Squash ?) mosaic virus infection in M. R. 45 cantaloupe. *A*. Reduction in size and distortion of surface and margins of leaves near the tip of a runner. Compare with normal leaf in right background. *B*. Mottling of leaf surface. Note also the curled margin.

become stunted and nonproductive.

Plants belonging to the Potato Family (*Solanaceae*) appear to be susceptible to more viruses than any other group. In Arizona, this is particularly true of tomato and potato. Tomatoes are susceptible to both cucumber (Plates X; XII) and tobacco (Plate IV, *B*) mosaic viruses, the two mosaic groups which appear to be most widely encountered in the field in Arizona. Both tobacco

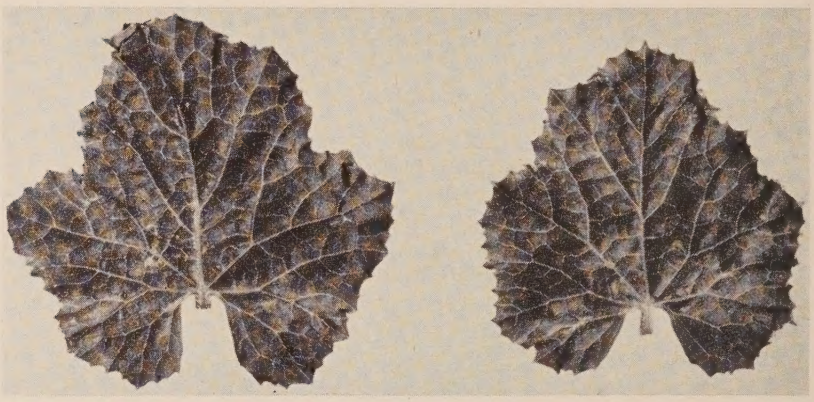

Plate II.—Scarcely perceptible mottle in leaves of muskmelon caused by an eastern strain of cucumber mosaic virus. (Photo by Bureau of Plant Industry, Soils and Agricultural Engineering, United States Department of Agriculture).

and cucumber mosaic viruses may be present simultaneously in a single plant, causing severe abnormalities.

Leaf Symptoms

Leaf surfaces—The leaf symptoms accompanying infections by mosaic viruses are usually most evident in young, actively growing plant parts. In melons and other vine-like plants symptoms are generally most pronounced at the tips of the runners (Plate I, *A*, *B*).

The earliest leaf symptom is a clearing of the veins during which these structures become transparent. This is followed by more pronounced and severe symptoms. Vein-clearing is rather difficult to detect in full sunlight and plants should be examined in partial or full shade.

One of the most prevalent and easily recognized symptoms of mosaic virus infections is the intermixing of the normal color of leaf and stem surfaces with areas of paler hues (Plates I-VIII, inclusive; XVII, XVIII). The absence of a uniform, normal, healthy coloration is known as mottling. The resultant patterns in mottled leaves and stems are called mosaics (Plates I-VIII inclusive; XVII, XVIII). The diseases themselves are known as mosaics and the pathogens causing them are termed mosaic viruses.

Mottling may be irregular, diffuse and scarcely perceptible (Plates I, *A*, *B*; II, III) or very distinct and brilliant, usually green and yellow (Plates IV-VII; VIII, A). As depicted in Plate VII, mottling may assume the form of dot-like areas. Similar symptoms may also result from the feeding of certain insects, particularly aphids on squash. The entire leaf surface between the veins may become yellowish leaving the regions immediately adjacent to the veins as green or greener than normal. This is called vein-banding (Plate VIII, *A*). This pattern may be com-

Plate III.—Faint yellow-mottle symptoms of mosaic virus infection in leaf from a seedling of Imperial 615 lettuce.

pletely reversed, the veins becoming yellow and the interveinal areas remaining green. This is termed yellow-vein (Plate VIII, *B*). Mottlings may at times assume the form of ring-like areas of alternating green and yellow bands (Plate XVII), or wavy, irregular lines (Plate XVIII). These symptoms are known as ring-spot and line-pattern, respectively.

Mottlings caused by strains of tobacco mosaic virus usually consist of brilliant yellow irregular areas interspersed among the normal green- or other-hued tissues. Such symptoms have been observed frequently in the field in Arizona in eggplant (Plate

Plate IV.—Brilliant yellow-mottle symptoms resulting from mosaic virus infections. *A*. Variegation-like sectoring in leaves of M. R. 45 cantaloupe. A healthy, noninfected leaf is at lower left. *B*. Portion of a leaflet of Pearson tomato, showing intensely yellowed areas due to infection by a strain of tobacco mosaic virus. *C*. Similar symptoms in a leaf of eggplant.

IV, *C*), pepper (Plate V, *A*) and infrequently in tomato (Plate IV, *B*).

The areas of normal green color among the abnormal ones are frequently raised and puckered (Plates I, *A*; VI, *a*, *b*). Symptoms of this nature are usually caused by strains of cucumber mosaic virus.

The entire aerial portion of a mosaic virus-infected plant may become paler than normal for that species. In such cases the

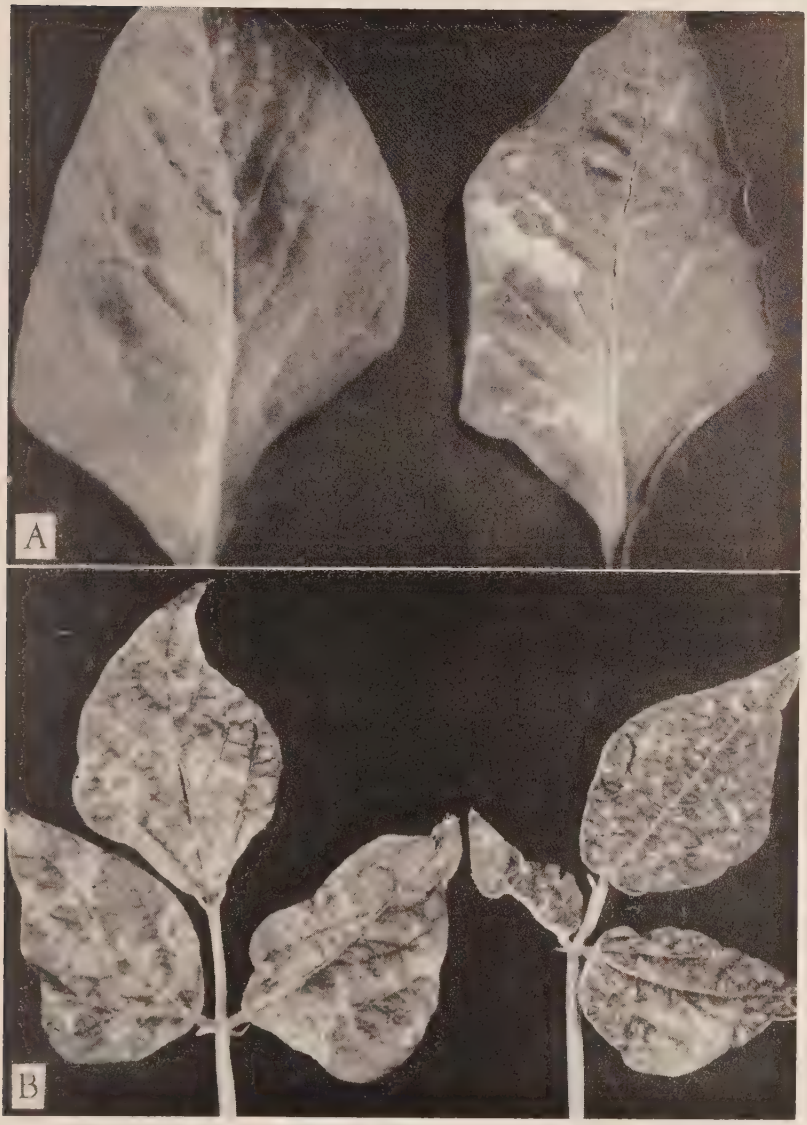

Plate V.—Brilliant yellow-mottle symptoms due to mosaic virus infections. *A*. Tobacco mosaic symptoms in a leaf of chili pepper (at right). Healthy leaf at left. *B*. Unidentified mosaic virus symptom expression in leaves of bean. (B: Photo by Dr. R. B. Streets).

Plate VI.—Symptoms of cucumber mosaic virus infection in cowpea. *a*. Distortion of leaf surface showing puckering. *b*. Brilliant yellow areas. (Photo by Dr. R. B. Streets).

Plate VII.—Dotlike symptoms (Stipple-mottle) composed of irregular, yellow spots in leaf of Patty Pan Squash.

discoloration is general and no mottling occurs (Cover, at right). In other instances, entire plants or plant parts may remain normal, green or even darker than normal. Such plants usually undergo extreme changes in form.

An unusual symptom which occurs in some mosaic virus infections is leaf scorch. This reaction is rather noticeable in early- to mid-season infections by the lettuce mosaic virus. Scorching of leaf tissue has also been observed in chili peppers infected with mosaic viruses in Cochise County. Generally, if it occurs at all, scorching follows mottling and other symptom types. This is a final symptom in some mosaic virus infections.

In addition to mottles and other leaf surface abnormalities, outgrowths sometimes occur on leaves infected with mosaic viruses. Such outgrowths are called enations. Enations also occur in some plants infected with viruses other than mosaics.

Plate VIII.—Unusual symptoms due to mosaic virus infections in leaves of cantaloupe. *A*. Vein-banding (dark-green areas along the veins with interveinal areas chlorotic). *B*. Yellow-vein symptoms especially noticeable in lower right of leaf in foreground. This symptom is also very common in leaves of watermelons in Arizona.

Plate IX.—Alterations in leaves of honeydew melons due to mosaic virus infections. Leaf at the lower right is healthy. Other leaves show various degrees of alterations in shape, size, and surface. Note the roughened vein effect in leaf at extreme upper right.

Leaf outline, margin and size—Some of the most severe effects of mosaic virus infections are expressed in extreme malformations of leaves. The entire shape of the leaf may be altered (Cover, at left; Plates I, *A*; IX, X). This modification may become so pronounced that the leaf blade is reduced to a mere threadlike strand and consists of little more than the mid-vein (Plate X). This symptom is called fern-leaf.

Margins of mosaic virus-infected leaves may curl inwardly toward the mid-vein, and either upward or downward. Marginal identations may become more numerous and finer than normal (Cover, at left) or the leaf indentations, especially lobes, may be reduced to a minimum (Plates IX, X).

Leaf outline modifications due to mosaic virus infections are generally accompanied by great reductions in leaf size (Plates I, IX, X).

Leaf veins—Leaf veins in mosaic virus-infected plants may be variable in number and are usually fewer than normal. Also, veins in infected leaves usually are roughened, coarse and enlarged (Plate IX, upper right). This symptom pattern is very common in potatoes infected with the virus-induced purple-top wilt in Arizona. Purple-top in Arizona potatoes is a multiple virus disease; part of the complex apparently being due to leaf-roll mosaic virus.

Internal symptoms caused by mosaic viruses in various plant structures are generally not observable in the field. These symptoms consist of deterioration of the food-conducting tissues as

Plate X.—Fern-leaf symptoms resulting from infection of tomato by a strain of cucumber mosaic virus.

well as of the bodies containing the chlorophyll.

Stem Symptoms

Stem surfaces—Stems of mosaic virus-infected plants may become mottled in much the same manner as leaves. Stem mottling does not appear to be as prevalent as leaf mottling in virus-infected plants in Arizona.

Stem structures—The main effect of mosaic virus infections in stems is a shortening of the internodes; the portion of the stem between the points at which leaves originate. This results in a bunching of the leaves, especially at the actively-growing stem tips.

Peculiarly flattened stems, the diameter of which exceeds the normal width by several times, have been observed in honeydew melons infected with yellow-mottle mosaic viruses in the Salt River Valley.

At times bud development at the tips of stems is suppressed by mosaic virus infection. For example, lettuce frequently fails to head when infected with lettuce mosaic virus.

Flower Symptoms

Symptoms of mosaic virus infections are highly variable in flowers. Infected plants may fail to flower at all, or if they do, the flowers appear prematurely or late. Two or more sets of flowers may be formed. Flowers of infected plants may be aborted and fail to produce seed. If some seed is produced, the viability is poor and some of the seed may contain active virus.

Mosaic-infected flowers may vary in size being either smaller or larger than normal. Aborted flowers are usually smaller than healthy ones.

By far the most spectacular reaction in flowers to mosaic virus infections, is the breaking in the normal color. Streaks or spots either lighter or darker than normal appear in the petals. Flower color break due to mosaic virus infection was first recorded in tulips in 1576. At the time the condition was not recognized as being a diseased state. Tulip growers soon discovered that the color-breaking properties of tulip mosaic virus could be perpetuated indefinitely through bulbs used for vegetative propagation. This fact was used as a tool in originating new highly variegated ornamental varieties which brought good financial returns to the producers.

Flower color in many ornamental plants, fruit trees, and even vegetables may be broken as a result of mosaic virus infections. Among the plants that may be affected are: stocks, pinks, sweet peas, pansies, flowering peaches, *Hippeastrum* spp., and larkspurs. Elberta peaches infected with mosaic also show this reaction.

A detailed discussion of virus-induced symptoms in ornamental plants and plants other than vegetables is deferred for future bulletins, excepting insofar as relationships to vegetable viruses are indicated.

Fruit Symptoms

Some of the most serious effects of mosaic virus infections are evident in fruits. Ordinarily, infected fruits are of abnormal shape (Plates XI, XII), are smaller than noninfected ones (Plate XI, *B*, *C*) and exhibit malformations on their surfaces (Plate XIII, *A*, *B*). A well-developed net is often lacking in cantaloupe fruits infected with mosaic viruses (Plate XI, *A*, *B*). In many cucurbits wartlike outgrowths appear on the surfaces of infected fruits (Plate XIII). This symptom is rather striking in squash (Plate XIII, *A*) and in watermelon (Plate XIII, *B*). Some fruits such as Persian cucumber, young cantaloupe, and honeydew may

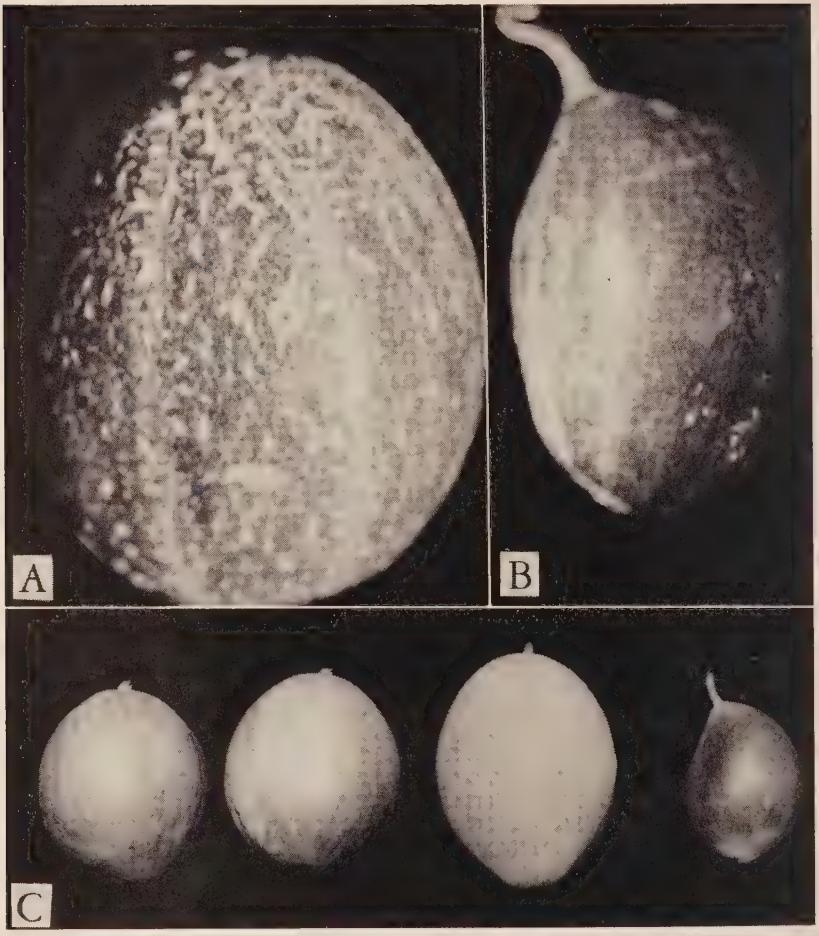

Plate XI.—Some effects of mosaic virus infections in fruits. *A*. Lack of well-formed net in cantaloupe. *B*. Distortion in shape and reduction in size of fruit of cantaloupe. *C*. Various abnormalities in honeydew melon fruits. The specimen second from the right is healthy and of normal shape, color and size.

become mottled but usually the mottling disappears as the fruits mature.

The greatest economic consequence of mosaic virus infections in fruits is in the low sugar content in such plants as cantaloupes and honeydew melons. Frequently the sugar content is so reduced that rejection at inspection time results. The fruit pulp in many instances in mosaic virus infections is paler than normal and the taste is insipid.

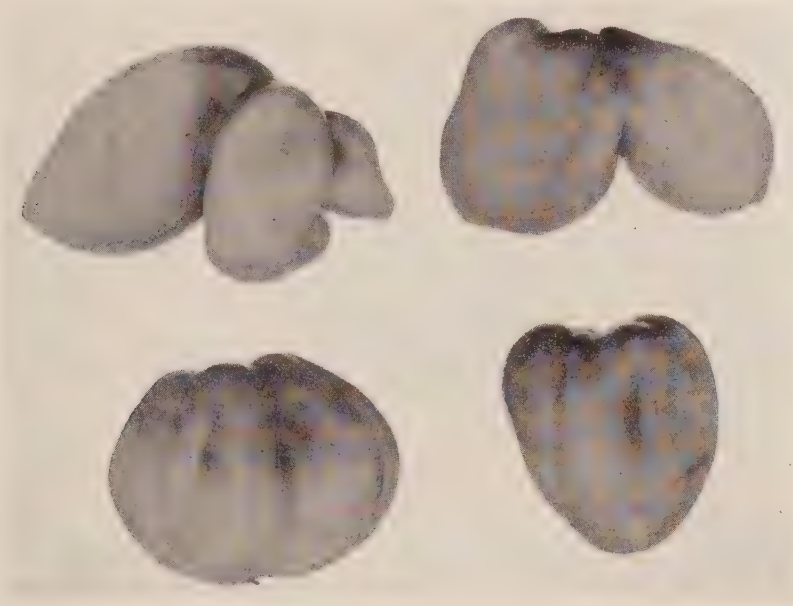

Plate XII.—Distortions in tomato fruits due to infection by the western cucumber mosaic virus. (From University of California Agr. Ext. Circ. 167).

Root Symptoms

Mosaic viruses appear to have little effect on roots other than stunting. When stunting occurs the normal root function is impaired. Carrots infected with mosaic viruses are usually paler in color than normal.

Even when symptoms are entirely absent virus particles are still present in roots. In this manner, roots frequently function as symptomless carriers.

HOW MOSAICS ARE SPREAD

Grafting is one method by which all viruses may be transmitted. Some additional methods by which mosaic viruses are spread from diseased to healthy plants are described in the following paragraphs.

Mechanical Transmission

It is believed that some sorts of wounds such as those caused by bruises, insect-feeding punctures, injured plant tissues due to the activities of man, machinery, wind, and other agencies, are necessary for mosaic virus infections in noninfected plants. In this respect the mosaic and other plant viruses are wound parasites.

Mere contact between a mosaic-diseased plant or plant part and a healthy individual is sufficient to create the conditions nec-

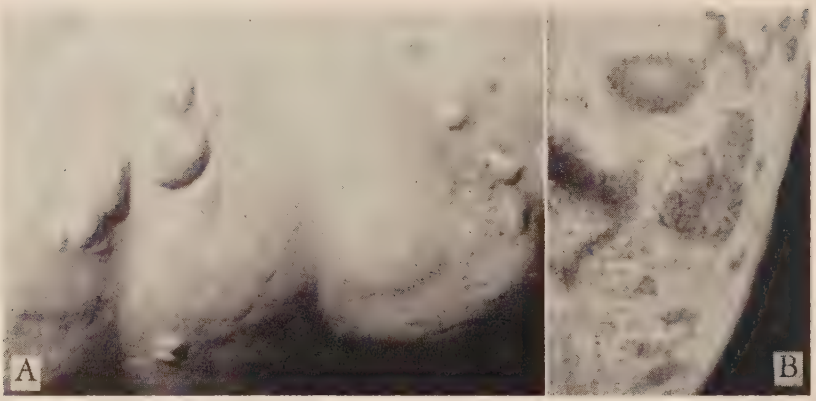

Plate XIII.—Wartlike protuberances on fruit surfaces due to mosaic virus infections. *A.* White, warty outgrowths on the surface of a portion of Patty Pan Squash fruit. *B.* Outgrowths on the surface of a portion of a fruit of watermelon.

essary for the spread of most mosaic viruses. Contact between closely spaced plants in the field due to growth pressures, wind, and other factors is sufficient to cause breaking of fragile plant hairs. The resulting wounds afford easy entrance for such viruses as tobacco and cucumber mosaic viruses.

Obviously caution should be exercised to prevent plant damage in conducting the usual and essential cultural operations connected with vegetable production.

Some strains of tobacco mosaic virus remain infective in tobaccos even after exposure to high temperatures and certain chemicals used in the process of curing. The spread of such virus strains may readily take place through smoking and chewing tobaccos which come into contact with healthy, susceptible plant tissues. In 1949, aucuba strain of tobacco mosaic virus appeared in tomatoes grown in a greenhouse in the Eloy district. This infection probably originated from the virus carried in tobacco used by workmen.

The use of tobacco by workmen during cultural operations in tobacco mosaic-susceptible crops like tomato, pepper, and eggplant, should be discouraged. Since tobacco mosaic virus can be carried in an infective state on body parts and clothing as well as in various forms of tobacco, the possibilities of introducing the virus into susceptible vegetable crops, ornamental plants and weeds, are numerous.

Both tobacco and cucumber mosaic viruses apparently remain infective in tomatoes for long periods at temperatures usually maintained in transit and subsequent storage. Diachum and Valleau (4) found both of these viruses to be still infective when recovered from green-wrap tomatoes after shipment across the United States.

The ease with which some of the strains of tobacco mosaic

virus are disseminated through carry-over in both processed and non-processed tobaccos accounts for the wide distribution of this virus in noncultivated susceptible plants at public gathering places throughout Arizona. Infected plants of wild tobacco (*Nicotiana glauca* Graham, Plate XVII) and Indian-apple (*Datura meteloides* DC., Plate XVIII), both of which are extremely susceptible to tobacco mosaic viruses, are common at numerous camp sites and viewpoints throughout the state.

Insect Transmission

Many mosaic viruses are transmitted by insects known as vectors. So far as is known, no strains of tobacco mosaic virus are insect-transmitted in Arizona. On the other hand, all of the cucumber mosaic virus strains as well as the viruses causing lettuce mosaic and others, are readily picked up from diseased plants and transmitted to healthy ones by numerous species of aphids (Plate XIV, *C, D;* XV) and some of the cucumber beetles.

There appears to be an association between vector and virus before the insect is able to infect a healthy plant after feeding on a virus-infected one. This association lasts from the time the insect picks up the virus from an infected plant then transmits and injects the virus into a healthy specimen. The interval of time required for this process is known as the latent period. In the case of mosaic viruses, the latent period is relatively short as compared with latent periods connected with other viruses. As a result, infective aphids are able to initiate disease in healthy plants almost immediately after feeding on a mosaic-infected specimen. For the grower a knowledge of the length of this period is desirable so that speedy control measures may be adopted.

In some cases the infectiveness of the vector is considerably enhanced by a short starvation period preparatory to feeding on a diseased plant. This starvation period may be as short as one minute but usually is as much as thirty. Starvation may actually occur in the field during flights of the vectors over areas of non-infected or non-susceptible crop plants, ornamentals and weeds.

Insects are believed to aid in spreading easily transmitted mosaic viruses merely by contact with the virus, resulting in external contamination of the body parts. In such cases the term vector is rather misleading, as much of the spread constitutes mechanical rather than biological association between the virus and vector.

Most mosaic viruses remain active in their vectors for only short periods of time. Very few vectors retain active mosaic virus in their bodies for periods longer than twelve hours. Usually the active period is much shorter, averaging around one-half hour.

Numerous species of aphids are known to be capable of transmitting mosaic viruses in regions outside of Arizona. Many of these occur in this state. Just which species are actually involved

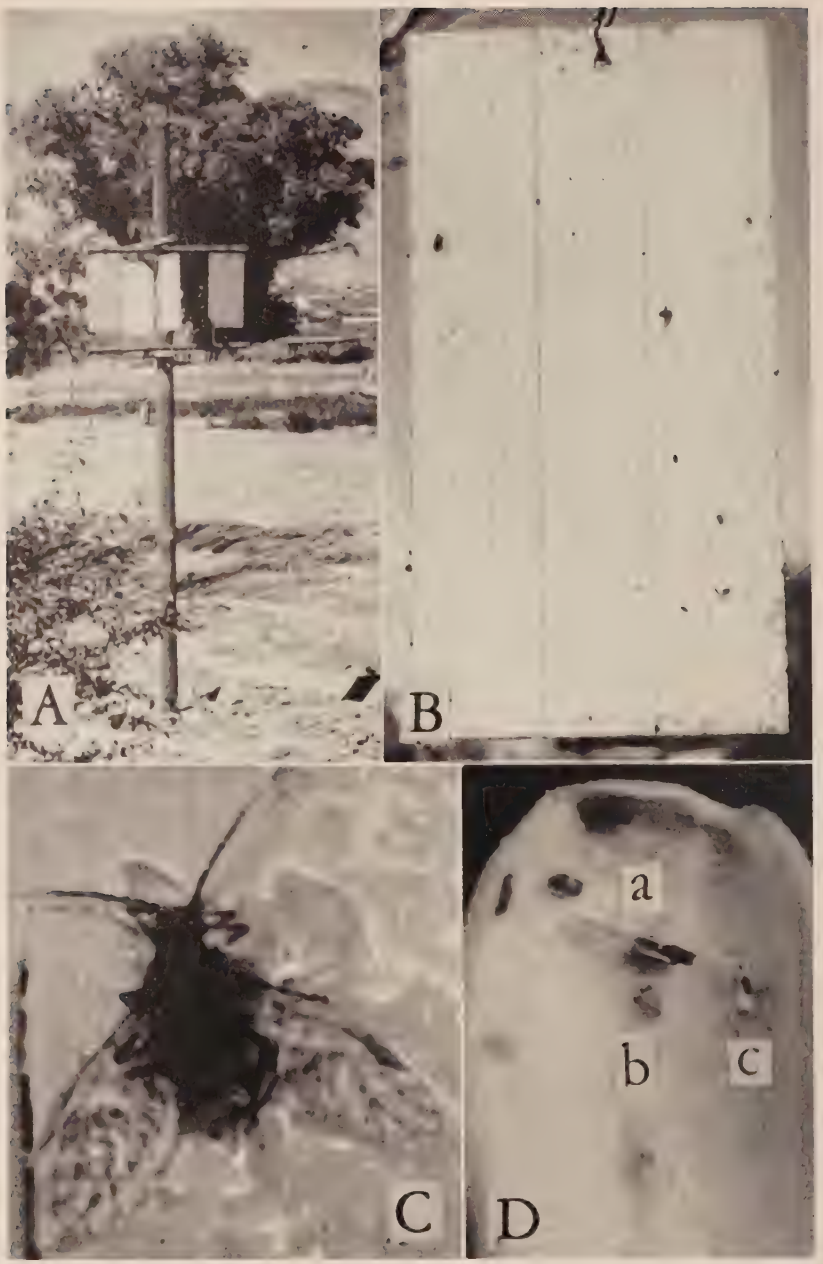

Plate XIV.—Apparatus used in studies of vectors of mosaic viruses in Arizona. *A*. Trap consisting of a support for four sticky boards; two at right angles to the others. *B*. A single sticky board showing entrapped insects. The vertical lines on the board surface are rulings made to facilitate the counting of specimens. *C*. A single winged aphid (greatly enlarged), entrapped in sticky material on board surface. *D*. Immature (wingless) and mature (winged) specimens of the pea aphid, *Macrosiphum pisi*, on a portion of a first seed leaf of M. R. 45 cantaloupe. This photo was made in connection with virus vector studies in a greenhouse at Tucson.

Plate XV.—Accumulation of aphids on the lower surface of a melon leaf.

as vectors of mosaic viruses in the irrigated areas of Arizona, is not fully known at this time.[3]

Studies in the Imperial Valley of California show that damage to melons from mosaic viruses depends to a great extent on the numbers of aphids in flight at any particular time as well as the numbers of flights during the growing season. In the Imperial Valley, it has been estimated (5)[4] that as many as 40,000,000 aphids may pass a line one-mile long in an hour, during the height of a flight. Thus far, such extreme numbers have not appeared with any consistency in the irrigated regions of Arizona, with the exception perhaps of the Yuma Valley.

The pea aphid, *Macrosiphum pisi* Kalt., has been shown at this Station to be an efficient vector of a yellow-mottle mosaic virus present in commercial lots of squash seed. This aphid is capable of transitting the virus to healthy cantaloupe and honeydew

[3] In co-operation with the Department of Entomology, University of Arizona, Tucson, studies have been conducted to determine what species of aphids are active over and in plantings of melons and lettuce. The equipment used was patterned after that previously adopted in the Imperial Valley of California and in Europe. Sticky board traps have been operated at various points in the crop-growing regions at Yuma and Phoenix. Similar traps (Plate XIV, *A*) were utilized at Tucson.

[4] Numbers in parentheses refer to "Literature Cited" at end of bulletin.

plants after a one- to five-minute feeding period on diseased squash seedlings.

Another common insect, the green peach aphid (*Myzus persicae* Sulz.), is known to transmit numerous mosaic viruses. In general, experiments have shown that the melon aphid, *Aphis gossypii* Glover (Plate XIV, *C, D*), a rather infrequent vector of melon mosaics in California (7), transmits the yellow-mottle mosaic found in squash seeds in Arizona. A few transmissions of this virus to cantaloupes were secured in a greenhouse at Tucson, particularly when this aphid was fed on diseased squash plants for a period of five minutes then transferred to first seedling leaves (Plate XIV, *C, D*). It is of interest that this same aphid has been shown to be a vector, although apparently a relatively inefficient one, of the virus causing Quick Decline of Citrus in California (6).

Most mosaic viruses are spread more readily by winged than by wingless aphids. The wingless and immature insects (Plate XIV, *D* at *b*) probably also play a role in picking up and transmitting mosaic viruses from diseased to healthy plants at least within the limits of their movements from without and within a crop. As with the winged forms, transmissions of viruses by wingless insects are probably both biological and mechanical.

In multiple-season crops such as lettuce in which new sowings and seedling plants are often adjacent to those where mature plants are being harvested, conditions are ideal for insect migrations and dissemination of mosaic viruses. Aphids active in fall-cutting lettuce have an opportunity to migrate to seedling plants of spring-cutting varieties. Obviously fields devoted to fall and spring crops should be separated as much as practical.

Some of the factors influencing aphid migrations and mosaic virus spreads in potatoes elsewhere (2) also account for the fluctuations in the prevalence of mosaic viruses in potatoes in Arizona. For example, leafroll mosaic and virus Y are more noticeable in early- than in late-planted potatoes. This is because young plants which are very susceptible to these viruses are present in the fields at a time when aphids are becoming active. The same factors apply to early- and late-planted lettuce with respect to spreads of lettuce mosaic virus. Fewer mosaic infections are to be expected at higher elevations than at lower ones as aphids are less active in the higher areas. Aphids are also usually less active during periods when winds are blowing.

Seed Transmission

Small percentages of seeds of a few species of plants are known to be infected with strains of viruses causing mosaics and certain other diseases. Although this point has been the subject of much speculation in the past, seeds undoubtedly serve as potential sources of mosaic viruses in Arizona in lettuce, cantaloupe, honeydew, squash, and bean. In lettuce from 1-8 per cent (averaging around 4) of the seeds may regularly contain mosaic viruses. In England, where lettuce mosaic is also prevalent, in-

fected plants set fewer seeds than healthy ones. As many as 15 per cent of the viable seeds produced by a single mosaic-infected plant, may contain virus (1). At the Arizona Agricultural Experiment Station, Tucson, two commercially-available lots of lettuce seed showed the following percentages of infection with seed-borne mosaic viruses. The seedlings were grown under virtually insect-proof conditions.

Lettuce variety	Number of seedlings examined for mosaic	Percentages of infected seedlings
Imperial 615	9,972	3.6
Imperial 749	10,209	2.2

In some varieties of beans and other legumes, the percentages of seeds containing mosaic viruses vary considerably. This is also true of melons and related cucurbits. In a single lot of Patty Pan squash seed from a reputable seedhouse in 1948 and 1949, 14.3 per cent were found in transmission experiments with cantaloupe and honeydew seedlings to be infected with one or more of the mosaic viruses (Squash mosaic ?).

At the Arizona Agricultural Experiment Station, Tucson, yearly tests have been conducted with commercial lots of melon seeds, to determine the actual percentages that are virus-infected. Both greenhouse and outdoor trials have been conducted with cantaloupe and honeydew melons. The percentages of infected seeds for 1949-52 inclusive, in a greenhouse are given in Table 1.

TABLE 1.—PERCENTAGES OF SEED-BORNE MOSAIC VIRUSES IN CANTALOUPE AND HONEYDEW MELONS IN THE GREENHOUSE

Year	M. R. Imperial 45 cantaloupe		Honeydew melons	
	Plants examined	Plants showing symptoms of mosaic	Plants examined	Plants showing symptoms of mosaic
	number	*per cent*	*number*	*per cent*
1949	397	0.5	399	2.5
1950	1,106	0.0	902	1.4
1951	313	0.6	801	3.4
1952 (Lot A)	245	6.1	292	7.1
1952 (Lot B)	—	—	503	6.7

Percentages of mosaic virus-infected plants of cantaloupe and honeydew melons in field tests where no attempt was made to control the activities of aphids and other vectors, from 1949-53 inclusive, are given in Table 2.

In these field and greenhouse experiments higher percentages of seeds of honeydew melons were infected than cantaloupes. In Arizona, fewer virus-infected seeds occur in sulphur-resistant

TABLE 2.—PERCENTAGES OF SEED-BORNE MOSAIC VIRUSES IN CANTALOUPE AND HONEYDEW MELONS IN THE FIELD

Year	M. R. Imperial 45 cantaloupe		Honeydew melons	
	Plants examined	Plants showing symptoms of mosaic *	Plants examined	Plants showing symptoms of mosaic *
	number	*per cent*	*number*	*per cent*
1949	4,102	0.8	2,291	1.6
1950	7,907	0.8	4,535	2.2
1951	16,027	0.6	7,512	1.6
1952	6,466	1.6	No tests made	
1953	22,489	5.3	965	4.5†

* Most of the seedlings were examined immediately after emergence and before aphids were very active. Since record taking consumed several days some of the last observations were made on plants which had become young vines.

† Late plantings in 1953 allowed more aphid spread by the time of harvest.

cantaloupe varieties such as V-1 and SR-91 than in mildew-resistant types like M. R. Imperial 45.

It is suspected that some of the seeds of certain noncultivated plants, such as wild gourds (Plate XVI) prevalent in Arizona are virus-infected.

There is obviously great danger of perpetuating and increasing mosaic viruses in Arizona through infected seeds. Even though only small percentages of seeds of some crop plants are infected with mosaic viruses, plants originating from them are important in setting up centers of infections. From these centers subsequent virus spreads may take place either by mechanical means or by insects. These seed-initiated centers of infection combined with other sources of virus such as ornamental plants and weeds, are of tremendous significance in the total build-up of mosaics, previous to, and at harvest time.

CONTROL OF MOSAICS

The term control may be misleading when applied to mosaic diseases. It is virtually impossible to completely control a mosaic virus once infection has been established in a planting. Although vegetable growers have become accustomed to specific spray and dust recommendations to alleviate losses from disorders caused by bacteria, fungi and insects, no single method of controlling most virus diseases is known. The virus picture is complicated by the fact that many are vectored by insects which actually serve as intermediate hosts. Then too, the virus particles themselves are *within* the insects and plant tissues and therefore are inaccessible directly to any chemical agents. Likewise, as the

Plate XVI.—Wild gourd, one of the desert-inhabiting, noncultivated plants, believed to be part of the melon mosaic virus picture insofar as seeds are suspected of harboring some of the strains of the viruses.

seed-borne mosaic viruses are within the seeds they are not affected by surface disinfectants. The picture is further complicated by the fact that symptoms exhibited by a virus-infected plant are the only evidence of illness. Frequently symptoms occur only after the virus has become well-established in the plant tissues. Control measures applied at such a late stage are ineffective.

Since control of most viruses is rather difficult and often impossible unless drastic measures, such as the total destruction of the crop are taken, attempts should be made to lessen the severity of attack. Some field observations have been made in the Salt River, Deer, and Yuma Valleys in connection with mosaics in lettuce, melons, and other crops. From these certain precautions suggest themselves.

Use of Disease-Free Seed

Seeds comparatively free from certain mosaic viruses are available on the market from reputable dealers. This is especially true in the case of lettuce and melon seeds. Some of the newer varieties of lettuce, however, seem to have a greater percentage of mosaic-infected seeds than do some of the older types. It is virtually impossible at this time to secure seeds of lettuce and melons completely free from mosaic viruses. Justham and Olgilvie (8) conclude in the case of tobacco mosaic virus in tomatoes that there is little difference in the amount of tobacco mosaic virus in plants grown from comparatively virus-free seeds and those from virus-infected lots. In spite of this, comparatively

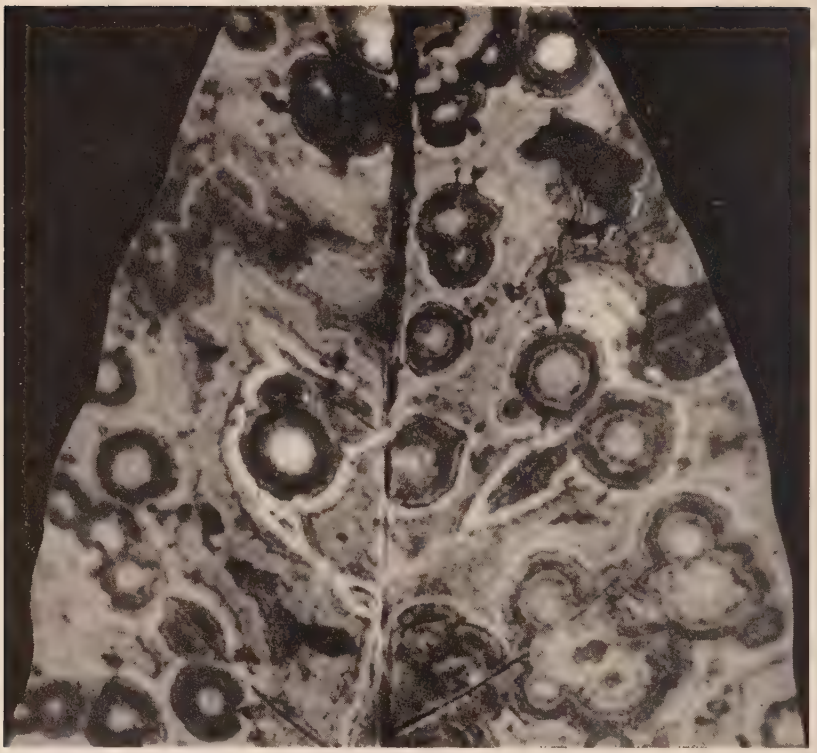

Plate XVII.—Portion of a leaf of wild tobacco (*Nicotiana glauca* Graham) showing symptoms of tobacco mosaic virus infection. Note the alternating bands of light and dark rings (in the field, yellow and green respectively), forming well-defined ring-spot patterns.

disease-free seed should be utilized whenever available. This will reduce as much as possible centers of infection which occur in fields from plants originating from inferior and contaminated materials.

Eradication

Most mosaic viruses completely invade their hosts. The surest protection against further spread once a virus has become established in a planting is the complete removal of all infected plants. In the case of lettuce and melon mosaics, infected plants should be dug up and allowed to die in place. This is to avoid handling and any subsequent accidental transmission. Dependable workers should be taught how to recognize mosaic virus symptoms and instructed to eliminate infected plants. If those plants which could act as centers of infection are removed periodically, subsequent virus spreads will be reduced to a minimum. The task of detecting mosaic-virus-infected plants is no more difficult than that of locating centers of red spider and other infestations.

Plate XVIII.—Single leaf from a tobacco mosaic virus-infected plant of Indian-apple (*Datura meteloides* DC.). Note the wavy, line-pattern effects in contrast to the ring-spot type caused by the same virus in another host. (Compare with Plate XVII).

Sanitation

Numerous weeds (Plates XVII, XVIII), ornamental plants and crops in addition to lettuce, melons, squash, eggplant, pepper, tomato, broccoli, cauliflower, spinach, and others are known to be susceptible to mosaic viruses. Many of them harbor mosaic viruses for variable periods of time. Perennials usually carry the viruses over winter months.

Many weeds, ornamental plants and even volunteer crop plants, in addition to serving as reservoirs for mosaic viruses also serve as plants where the virus vectors carry on their usual activities such as multiplying and feeding. The elimination of weeds and volunteer crop plants as well as ornamentals from within and around a planting is therefore an essential step in reducing losses from mosaic and other viruses. Weeds and other

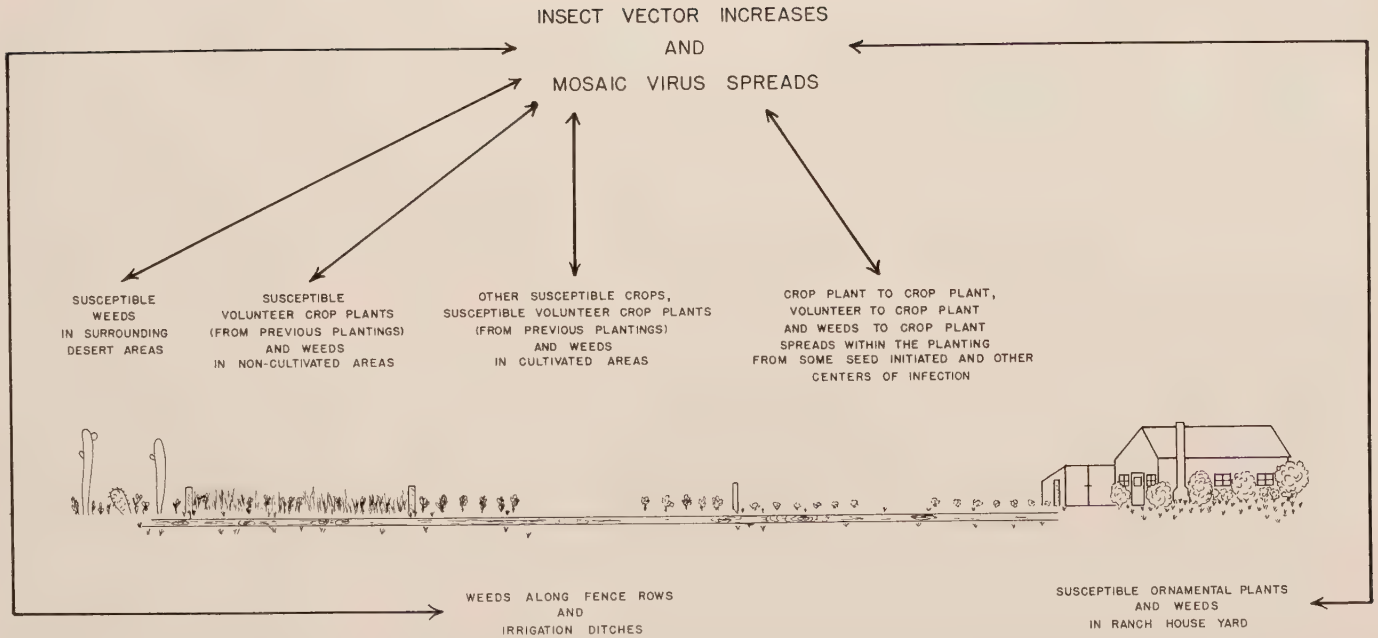

Figure 1.—Schematic representation of various factors involved in the transmission of mosaic viruses and in the activities of the vectors. The part played by weeds, volunteer crop plants, and ornamentals in areas adjacent to or near the main crop fields, in aiding the spread of mosaic and other viruses, is highly significant.

susceptible plants also should be eliminated from near-by non-cultivated areas surrounding a crop to be protected. Figure 1 shows schematically how the various sources of both virus and vectors may interact to influence mosaic virus spreads. The weeds in surrounding desert areas may be as much involved in virus infections as those immediately surrounding the crop or within the planting itself. Ornamental plants in nearby ranchhouse yards may also harbor both viruses and vectors.

Many interesting vegetable virus-ornamental plant-weed relationships exist. For example, sweet peas are susceptible to lettuce mosaic virus as well as the pathogen causing spotted-wilt in tomatoes and other hosts. The mosaic viruses are actually highly desirable in sweet pea cultures because they produce unusual flower effects. Thus, while certain mosaic viruses may be desirable to the sweet pea grower, planting of this ornamental near lettuce and other susceptible crops may prove very hazardous and detrimental to the vegetable grower. Some of the cucumber mosaic virus strains which infect pansy, petunia, violet, delphinium, and other ornamentals, also attack cantaloupe, honeydew melon, watermelon, squash, and other vegetables. The elimination of such ornamentals from around susceptible vegetable crops is essential in the control of cucumber mosaics.

Whenever possible a mosaic-susceptible crop should not follow a previous mosaic-susceptible crop in the rotation scheme. The importance of volunteer crop plants from a previous planting aiding in the dissemination of mosaic viruses in a subsequent crop should not be ignored by the grower. In addition the housewife should be concerned with the possibility of mosaic-susceptible ornamental plants escaping from the ranchhouse yard into near-by fields and fence rows.

Isolation of Crops

Crops susceptible to mosaic virus attack should be as far removed from other mosaic-susceptible and vector increase plants as is practical and as land utilization will permit. For instance, honeydew melons should not be planted adjacent to or near other mosaic-susceptible crops such as cantaloupe, squash, cucumber, pepper, bean, tomato, and others. Also melons should not be planted near fields of alfalfa, sugar beets, or carrots. All of these are excellent crops for the activities of the vectors which transmit the mosaic viruses. While such crop separation is difficult in many large-scale plantings in areas like the Salt River, Deer, and Yuma valleys, some degree of isolation is possible and should be practiced.

Figures 2 and 3 illustrate the disadvantages in locating main crops near or adjacent to those of other mosaic-susceptible and aphid-preference plants. Examination of the figures reveals higher average percentages of mosaic-infected melons in the vicinity of plantings of alfalfa, carrots, sugar beets, and desert areas.

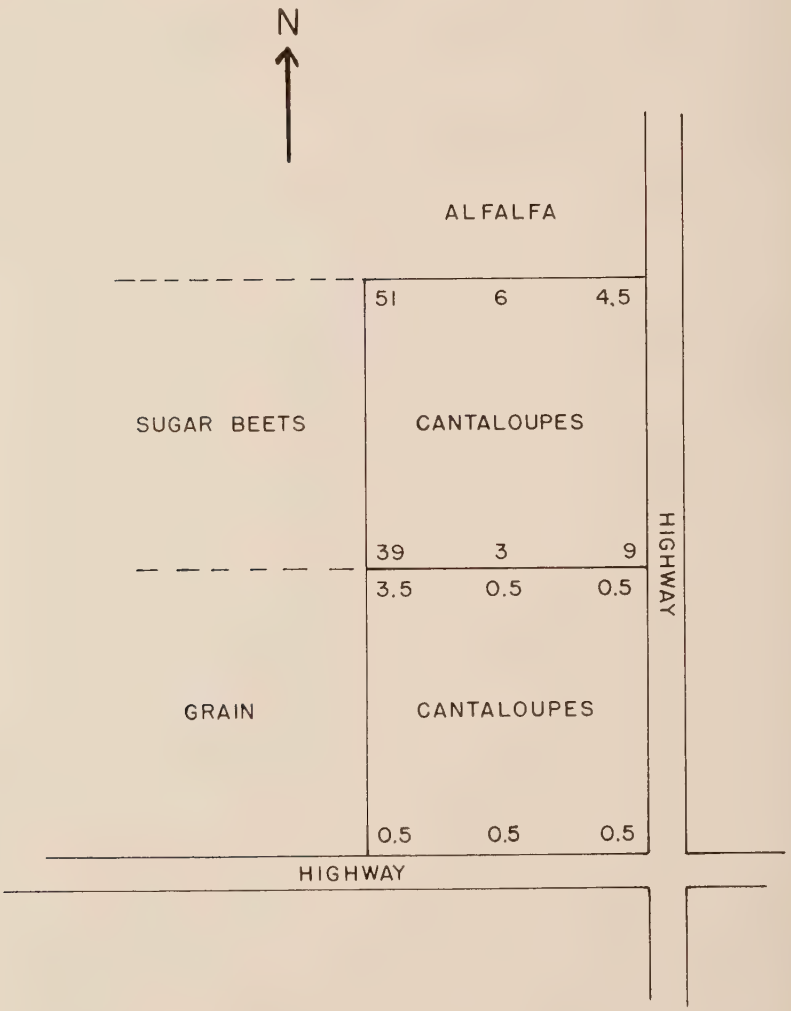

Figure 2.—Average percentages of mosaic virus-infected Imperial 45 cantaloupe plants in various positions in two 40-acre stands. Based on randomized counts of 400 plants (200, two weeks previous to harvest; 200, after the first two pickings). Note the influence (reflected in higher average percentages of infected plants) of nearby aphid-favorable crops, such as sugar beets and alfalfa.

Plantings of mosaic-susceptible crops also should not be made near excessively weedy areas, unless some provision for the elimination or control of the weeds is made.

Broadbent (1) found that seeding lettuce in large, widely separated blocks greatly facilitated mosaic control. In Arizona, fields devoted to fall-cutting lettuce should be separated as much as is

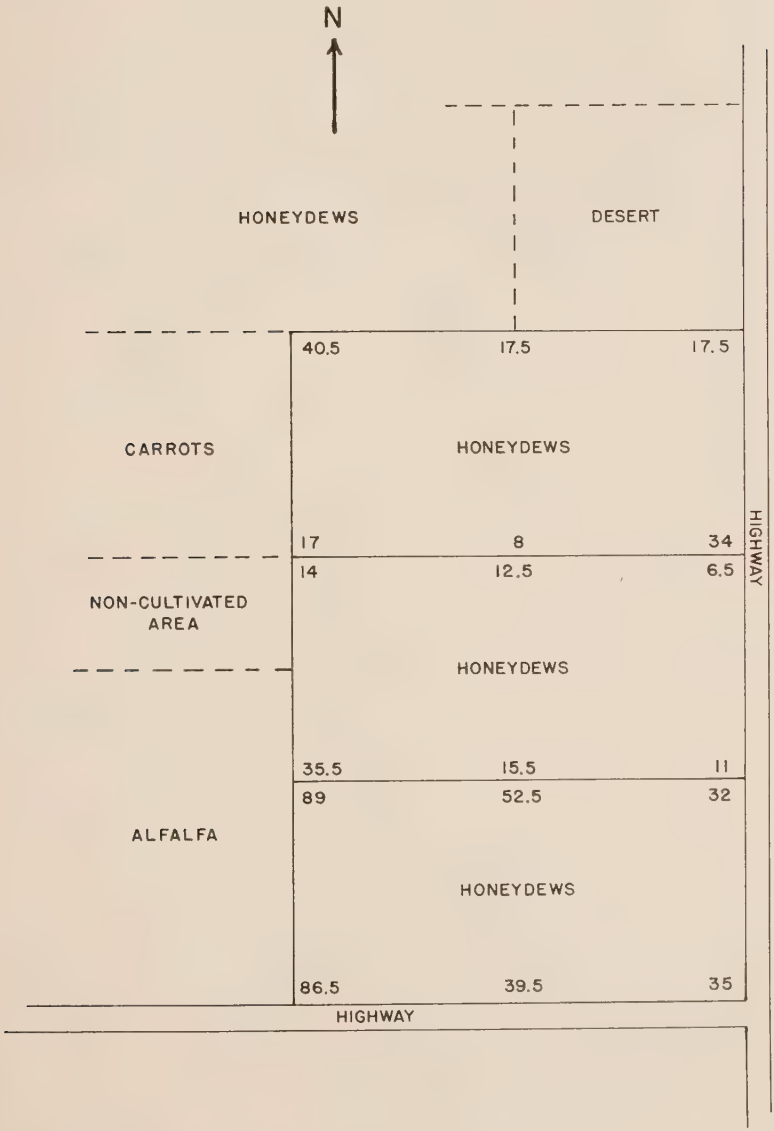

Figure 3.—Average percentages of mosaic virus-infected honeydew melon plants in various positions in three stands. Average percentages based on randomized counts of 400 plants (200, two weeks previous to harvest; 200, after the first two pickings). The proximity of fields of alfalfa and carrots as well as other honeydew plantings and desert areas, has had an effect on the amount, prevalence and distribution of mosaic. All of the nearby crops are excellent for aphid activities; some harbor the mosaic viruses themselves.

practical from those devoted to the culture of the spring-cutting crop.

Table 3 lists some of the vegetables commonly grown in Arizona and the mosaic viruses likely to attack them. In the case of cucumber mosaics or other insect-vectored viruses, reference to the respective columns will indicate what crops should be in isolated plantings. Vegetables susceptible to the same viruses should be in separated areas.

Since the tobacco mosaic viruses are not insect-transmitted at least to any extent in Arizona, the separation of susceptible crops is valueless. Nevertheless, it should be borne in mind that strains of tobacco mosaic may be spread by mechanical means and perhaps in wind-blown fragments of infected plant tissue. These means of spread are rather restricted so that the chances of tobacco mosaic virus transmission between susceptible crops in close proximity are far less than with the truly insect-transmitted types such as cucumber and lettuce mosaic viruses.

Insecticides

The use of an appropriate insecticide to protect a crop against migrating mosaic virus vectors would appear to be the most direct approach to controlling these diseases. Unfortunately, this comparatively simple procedure is usually ineffective against such vectors as aphids. Only small numbers of aphids and other vectors are essential to the successful spread of mosaic viruses in significant amounts from infected to healthy plants. It has been amply demonstrated that present-day insecticides applied to such crops as melons (5, 7) and lettuce do not alter the mosaic virus picture appreciably. The few infective vectors that survive will be able to spread mosaics.

If insecticides are used they should be applied first directly to the crop to be protected and subsequently to the surrounding vegetation, whether consisting of weeds or ornamentals.

Barriers

Physical or natural barriers such as buildings, trees, hedges and mountains, surrounding a planting interfere with the movement of insect vectors of viruses. In lettuce, Broadbent, *et al.* (3) have shown that such barriers influence the distribution of mosaic-infected lettuce plants in a field. Barriers hinder aphid flights to such an extent that at times these insects either do not reach the crop, or if they do, they tend to feed on those plants which are most readily available to them, nearest the barriers. As a result, most mosaic virus damage may be expected in those plants immediately adjoining fence rows, trees, mountains, buildings, and other obstructions. In melons this relationship is more apt to prevail in cantaloupes than in honeydews. In honeydew melons so many seed-initiated centers of infection occur that there is no obvious correlation between the amount of mosaic in vines and the density of the surrounding areas.

Resistant Varieties

The ideal method sought for the control of most plant pathogens is the development and use of disease-resistant plants. At the present time there are few plants resistant to virus attack. In certain instances, varieties of vegetables and agronomic crops have been developed which have withstood virus attacks under local conditions in the areas in which the plants have been bred. Among these are the following varieties of beans reputedly resistant to most forms of mosaic viruses as well as to the virus causing curly-top.

Great Northern	Pinto	Red Mexican
U. I. 15	U. I. 72	U. I. 3
U. I. 16	U. I. 78	U. I. 34
U. I. 31	U. I. 111	
U. I. 123		

These beans have been developed at the Idaho Agricultural Experiment Station and are being tested for their adaptability to the northern bean-growing areas of Arizona. Thus far, the Pinto lines have outyielded the commonly accepted Colorado Pinto.

Other crop plants reportedly resistant to mosaic viruses are Virginia Savoy Spinach, resistant to spinach blight mosaic virus; Shamrock Cucumber, resistant to various cucumber mosaic viruses; and Idaho Refugee and Wisconsin Refugee No. 5 beans, both of which are resistant to some forms of bean mosaic virus. Oddly enough, the two vegetables bringing in the greatest cash income to the Arizona grower, namely lettuce and melons, are the very ones for which few virus-resistant stocks are available. Seeds comparatively free from mosaic viruses are high priced and in some instances relatively non-available.

Crop-Free Periods

Control of some virus diseases, especially western celery mosaic has been secured through the imposition of periods when the crop must not be grown. These periods have been selected so that plants will be in the field when aphid activity is much reduced. In California, the growing of celery is forbidden in specified regions in glass houses during the period of August 20 to September 19 and in the field from August 20 until November 19. The shorter period for glasshouses is allowable because the virus is not seed-borne and the grower can thus secure an early start free from aphid interference in getting plants ready for field use. By the time plants are ready to be set out, aphid activity will be at a minimum. Although carrots are also susceptible to the same virus, the crop-free periods for celery afford a chance for the western celery mosaic virus to become inactive during the absence of the most prevalent host, celery. Some mosaic will develop in celery plants near the end of the growing season but not in sufficient amounts to cause appreciable damage.

The mere moving of mosaic-susceptible crops from one region to another appears to aid in reducing losses in cantaloupes and other crops in Arizona. This does not appear to be effective in honeydew mosaics as the initial amounts of the virus present in seeds of this crop afford ample centers of infection for secondary spreads by aphids and other vectors in old or new localities.

Other Recommendations

In general, the adoption of cultural practices which tend to reduce to a minimum the handling of mosaic-susceptible plants, will aid in reducing mosaic damage. If an established infection is noted and appears to be localized, cultural practices should be such that workers will move towards the infected area and away from the noninfected one. If cantaloupes and honeydew melons must be worked at approximately the same time, the cantaloupes should receive first attention, then the honeydews. Usually there are fewer centers of infection in a cantaloupe planting and the chance of mechanically carrying infections to honeydews from cantaloupes is less than that of carrying infections from honeydews to cantaloupes.

Direct seeding in the field of a mosaic-susceptible crop which is normally transplanted may aid in reducing losses from mosaic viruses. The less such crops are handled, the fewer are the chances for mechanical transmissions. For example, tomatoes which have been seeded directly in the field usually show less tobacco mosaic virus infection than do transplants. In England, Broadbent (1) has recommended that lettuce seedlings for transplanting be dipped in nicotine solution, to aid in ridding them of aphids. The direct seeding of plants in the field in Arizona accounts in no small measure for the absence of marked secondary spreads of some of the mechanically-transmitted mosaic viruses.

Trap crops susceptible to the mosaic viruses capable of attacking a crop to be protected will tend to divert the attention of the first wave of insects seeking to feed. The same is true of some non-susceptible crops. The chief disadvantage of this method of mosaic control is that virus-susceptible trap crops themselves become reservoirs for the viruses which may then be transmitted to the main crop. One to several rows of a trap crop are usually planted around the main area.

Certain chemicals have been injected into plants infected with viruses with some success in inducing recovery from severe symptoms. Kassanis (9) has found heat to be effective in eliminating leafroll mosaic-virus from infected potato tubers. Potato leafroll occurs in Arizona at times.

If any doubt exists as to the virus origin of a disease in plants, specimens should be sent to the Department of Plant Pathology, University of Arizona, Tucson, for study and diagnosis.

ACKNOWLEDGMENT

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APPENDIX

TABLE 3.—MOSAIC VIRUSES REPORTED IN ARIZONA VEGETABLES

Vegetable	Mosaic viruses reported			Vegetable	Mosaic viruses reported		
	Cucumber:	Tobacco:	Others		Cucumber:	Tobacco:	Others
Artichoke	—	—	—	Lettuce, Head	—	—	+
Asparagus	—	—	—	Lettuce, Leaf	—	—	+
Beans, Bush	+	—	+	Muskmelon	+	—	—
Beans, Pole	+	—	+	Mustard	—	—	—
Beans, Lima	+	—	+	Okra	—	—	—
Beans, Soy	—	—	—	Onion	—	—	—
Beets, Garden	—	—	+	Parsley	—	—	—
Beets, Sugar	+	—	+	Parsnip	—	—	—
Broccoli	—	—	+	Peas	—	—	—
Brussels Sprouts	—	—	—	Peanuts	—	—	—
Cabbage, Green	—	—	+	Pepper, Bell	+	+	—
Cabbage, Chinese	—	—	—	Pepper, Chili	+	+	—
Cantaloupe	+	—	+	Potato, Irish	—	—	+
Carrot	—	—	+	Potato, Sweet	—	—	—
Cauliflower	—	—	+	Pumpkin	+	—	+
Celery	+	—	+	Radish	—	—	—
Chard	—	—	—	Rhubarb	—	—	—
Cucumber	+	—	—	Rutabaga	—	—	—
Eggplant	—	+	—	Salsify	—	—	—
Endive	—	—	—	Spinach	+	—	—
Garlic	—	—	—	Squash, Summer	+	—	+
Horseradish	—	—	—	Squash, Winter	+	—	+
Kale	—	—	—	Tomato	+	+	—
Kohlrabi	—	—	—	Turnip	—	—	—
Leek	—	—	—	Watermelon	+	—	—

+ Occurs in this vegetable in Arizona.
— Never reported in this vegetable in the state.

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